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Flexible decision support for sustainable development: the SUSTAIN framework model

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Sustainable transport planning necessitates a rethinking of traditional decision making. This is conventionally supported by cost-benefit analysis (CBA) that systematically quantifies and compares the various benefits and costs generated by a transportation project or policy. Generally, CBA has been found less useful for the handling and assessment of multiple, often conflicting objectives or criteria like environmental or social issues intrinsically difficult to quantify. Therefore, it is necessary to broaden the decision making process beyond merely economic factors. The Danish research project on Sustainable National Transport Planning (SUSTAIN 2012-2016) seeks, among other things, to develop a flexible decision support model (tool) to include and assess sustainability planning criteria in a socio-economic framework, which makes up the SUSTAIN Framework Model (SFM). The SFM comprises two parts, namely a process part consisting of stakeholder involvement and an analytical tools part consisting of an Excel-based software model. The latter employs the use of CBA, multi-criteria decision analysis and risk analysis techniques enabling the assessment of non-quantifiable impacts within a decision support context. The concept of a planning workshop is introduced as relevant for dealing with the various strategic elements not included in the CBA. Moreover, SUSTAIN is rooted in cross-disciplinary sustainability research that recognises that a transition towards sustainability must involve normative, analytical and strategic considerations to be successful. The paper concludes that the SFM can contribute to the analytical dimension. Thus, the framework model allows for the appraisal of planning criteria (indicator sets) in a socio-economic appraisal setting for national sustainable transport planning which enhances both the concept and principles of sustainable development while at the same time it provides a flexible decision-support tool for policy-makers.

Keywords: *Sustainable transport planning, Decision and policy support, transport planning and appraisal, the SUSTAIN framework model, MCDA, CBA.*

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1. Introduction

Conventional decision support for transport infrastructure projects is based on the use of cost-benefit analysis (CBA) (Grant-Muller et al., 2001). However, today's decision-makers (DMs) are expected to be economically responsible when taking decisions – but also socially and environmentally responsible with regard to equity and sustainability. In most real-world policy situations there are many alternatives, many uncertainties, many stakeholders and many consequences of interest (Walker, 2000). Together with the fact that there is usually no single decision-maker, this means that achieving agreement will typically be based on a number of factors – or decision criteria – which make multi-criteria decision analysis (MCDA) become a useful tool for the decision-makers.

MCDA should not be seen as a prescriptive answer (often there is no optimal solution), but as a transparent and informative framework when including analytical modules embedded in a decision process (Belton and Stewart, 2002). The purpose of such a framework is to enable people to uncover their intuitive decision procedures by being informed following a structured rational analytic process (Ananda and Herath, 2009). MCDA helps decision-makers choose one course of action from among many, often complex possibilities. Important in this respect is that MCDA is a decision aid that in no way aims at replacing the judgement of the decision-makers.

Several attempts to integrate CBA and MCDA in a transport appraisal scheme has been made in the past, see e.g. Barfod and Salling (2015), Gühnemann et al. (2012), Leleur (2012; 2015), Sanchez-Lopez et al. (2012), De Brucker et al. (2011), De Brucker and Verbeke (2007), Tsamboulas (2007), Janic (2003) and Sayers et al. (2003). MCDA is based on value measurement using qualitative input from a ratifying group, and is a widely used methodology for assessing impacts that only with great difficulties can be quantified (Belton and Stewart, 2002). However, MCDA is not a fixed part of the appraisal scheme for infrastructure projects in all countries. In countries with long traditions for CBA (e.g. Sweden and Denmark) the methodology is not yet fully accepted as a valid decision aid due to its dependence on subjective qualitative input. However, many stakeholders take part in the debate concerning infrastructure projects although they are not formally included in the appraisal process. Thereby important information which can improve the decision support can be overlooked. MCDA provides an approach for embedding these stakeholders' viewpoints in the appraisal process. The framework proposed in this paper provides the possibility of modelling informed decision support by allowing for the process to be expanded beyond the consideration of the conventional economic factors and allowing for stakeholder participation. The framework makes use of a set of techniques that can be customised to the specific decision task at hand and for this reason no specific MCDA technique is linked to the model. The appraisal process is supported by the concept of a planning workshop, which is used for generating input to the decision support model. The planning workshop concept as described by Phillips (2007) in the form of a decision conference has previously been proposed applied to transport planning situations e.g. by Barfod (2012b) and Barfod and Salling (2015).

Additionally national transport planning and decision making is challenged by the need to include a sustainable development dimension of the transport system. This has been a demand from many governments in recent years. In Denmark, the Government and Parliament have reconfirmed this ambition in an infrastructure plan on "Sustainable transport" and a political agreement on a "Green Transport Policy", which was decided in 2009. Thus national transport planning has to adopt principles of sustainability, making it highly relevant to outline the contents of national sustainable transport planning (NSTP). The Danish research project on Sustainable National Transport Planning (SUSTAIN 2012-2016) seeks, among other things, to develop a flexible decision-support tool to assess sustainability indicators in a socio-economic framework, referred to as the SUSTAIN Framework Model (SFM). The aim of SFM is two-fold, firstly to provide decision support for those participating in the decision process and to embed sustainability concerns into the decision support, and secondly, to provide a transparent decision support which is able to communicate the reasoning behind the decision for those not participating in the process.

In SUSTAIN (2012-2016) NSTP has been defined as: frameworks, procedures and activities that seek to: "…integrate sustainability in the design and implementation of comprehensive national transport polices and plans" (Hedegaard et al., 2013).

SUSTAIN, hence, has adopted a cross-disciplinary research approach that recognises that transition towards sustainability must involve normative, analytical and strategic issues (dimensions) to be interlinked to make NSTP successful. This paper mainly concerns the analytical dimension with a focus on the SFM. Specifically, the framework allows socio-economic and sustainable appraisal to be carried out based on criteria sets derived from indicator sets that comprise national transport objectives which can be categorised as economic, environmental or social. By using the framework model decision-makers get actively involved in the decision-making process, and therefore they can become aware of the sustainable development conflicts to be managed and the trade-offs to be made (De Brucker et al., 2013). The decision-makers are in this context the politicians, who take the final decisions as a result of settlements between conflicting interests. In addition to these other stakeholders such as environmental organisations etc. should also participate in the process (Barfod, 2012a).

A schematic and indicative view of the challenge of NSTP can be presented by two planning approaches, which illustrate some principal differences between what can be termed conventional transport planning, to be referred to as a business-as-usual (BAU) approach, and a sustainable development (SD) type of planning approach. The schema below in Table 1 is based on Banister (2008) and Marshall (2001).

Table 1. Two transport planning approaches: Business-as-usual (BAU) and Sustainable Development (SD) (Banister, 2008)

Conventional approach – Transport planning and engineering (BAU)	An alternative approach - Sustainable mobility (SD)
Physical dimensions	Social dimensions
Mobility	Accessibility
Traffic focus, particularly on the car	People focus, either in (or on) a vehicle or on foot
Large in scale	Local in scale
Street as a road	Street as a space
Motorised transport	All modes of transport often in hierarchy with pedestrian and cyclist at the top and car users at the bottom
Forecasting traffic	Visioning on cities
Modelling approaches	Scenario development and modelling
Economic evaluation	Multi-criteria analysis to take account of environmental and social concerns
Travel as a derived demand	Travel as a valued activity as well as a derived demand
Demand based	Management based
Speeding up traffic	Slowing movement down
Travel time minimisation	Reasonable travel times and travel time reliability
Segregation of people and traffic	Integration of people and traffic

The transport planning process consists of many activities that are interconnected, which is illustrated in Figure 1 stemming from (Khisty et al., 2012, p. 538). As can be seen the appraisal can be carried out with respect to several types of study issues; as concerns the SFM this is illustrated later on with three different case studies. The appraisal framework is developed as a generic type of appraisal tool so it can also handle policies and in principle all the different types of appraisal issues referred to in Figure 1.

The paper is structured as follows. After this introduction Section 2 presents the SUSTAIN framework model (SFM). In Section 3 the SFM is subsequently applied to three different case studies to illustrate the flexibility. Finally, conclusions and perspectives for the framework is set out in Section 4.

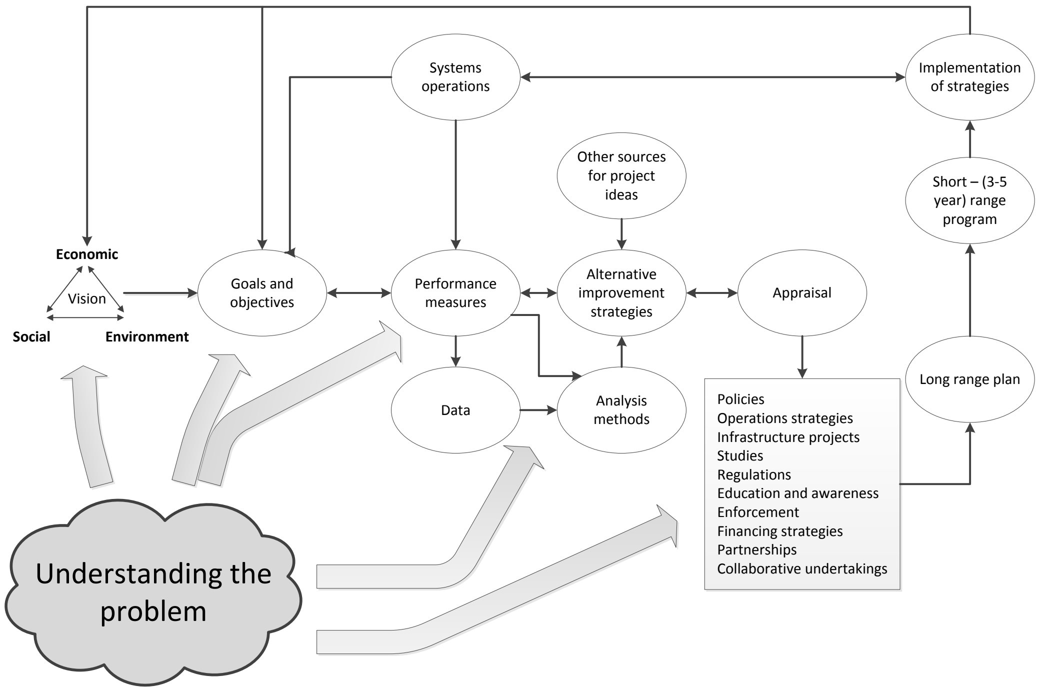

Figure 1. Appraisal as part of the overall transport planning process (Adapted from Khisty et al., 2012)

2. The SUSTAIN Framework Model

The SUSTAIN framework model (SFM) consists of a methodology which processes inputs from the participants within a planning workshop similar to that of a decision conference as suggested by Phillips (2007). The difference between the planning workshop and the decision conference lie in the context in which it is applied. The decision conference concept is originally develop for use in the private sector where decisions actually are made at the conferences. However, Barfod (2012a) found that when applying the concept in a public context the outcome is often not a decision, but instead a recommendation for further action to the decision-makers. Thus, the designation of a planning workshop is more appropriate to use.

The SFM is Excel-based and contains a CBA-module, a MCDA-module based on a variety of techniques that can be applied depending on the context of the decision problem and a quantitative risk analysis module made use of to explore factors of uncertainty e.g. cost estimates. The process-based planning workshop specifically handles the subjective parameters from the applied methodologies. Therein lies the interpretation and hence selection of criteria specifically related to the case study/initiative to be assessed. Thus, a special concern in relation to SFM is the set and thereby compilation of planning criteria made use of.

2.1 Sustainability assessment and overall approach

Several efforts have been made to translate the various existing definitions of sustainability into applicable criteria or indicators for assessing the sustainability of projects or policies. The Swiss Government's Sustainable Development Strategy (Swiss Federal Council, 2008) and The Transportation Research Board guidebook for sustainability performance measurement (Zietsman et al., 2011) are good examples on sustainability indicators. However, there is often difficulty in identifying suitable data sources for appropriate indicators. Salling and Pryn (2015) propose a Long List of criteria, which has been set up for sustainability assessments (see Figure 2). The purpose of the list is to support the work by providing a broad range of national transport planning objectives found relevant for making sustainability operational in appraisal of large transport infrastructure projects in the context of national sustainable transport planning (NSTP).

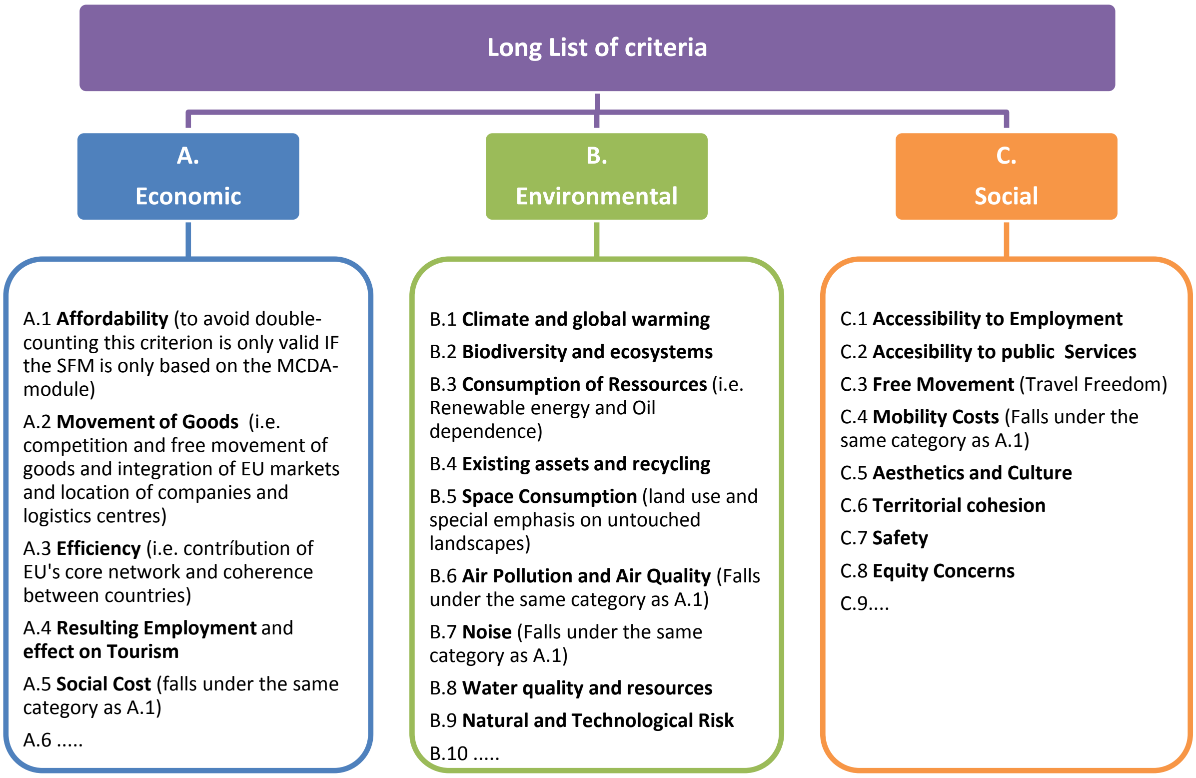

Figure 2. Excerpt of the Long List of criteria elaborated with respect to the three traditional pillars of sustainability: economic, environmental and social (adapted from Salling and Pryn (2015) and Pryn (2013))

The appraisal study begins with a CBA, which is the conventional way of examining socio-economic feasibility of a transport infrastructure project in Denmark. This analysis is based on a well-established methodology, which will lead to economic index values indicating the examined project's socio-economic performance. One of these is the benefit-cost ratio (BCR). The BCR result is examined by use of Monte Carlo simulation, where transport demand and investment costs are explored based on their variability (Salling 2008; Salling and Banister, 2009). In this analysis so-called certainty values are provided which can be used for comparing the socio-economic robustness of the alternatives. The certainty value indicates the probability (or likelihood of occurrence) that the BCR is at least equal to 1.00, serving as the cut-off for socio-economic feasibility (Salling and Leleur 2015).

The Long List of criteria has been produced based on including criteria commonly made use of in the Scandinavian and several other European countries. Furthermore, a number of criteria are based on the EU Roadmap (European Commission, 2009), for which reason their formulation and description can be seen to follow this text.

The 'vision' for a new transport infrastructure project is illuminated by selecting a Short List of criteria based on the Long List. Typically, this vision is assisted by scenario thinking, which is used as a tool for visualising and assessing possible futures under different conditions

(Bohunovsky et al., 2011). Some scenarios to exemplify can be: Business-as-usual (BAU), Sustainable development (SD) and Crisis and stagnation (CS) which have been further elaborated in (Salling and Leleur 2017). For each vision/scenario/development strategy the most relevant criteria are selected. To this list is then added the socio-economic certainty value as a separate criterion (Salling and Banister, 2009). This set of criteria is then weighted in accordance with their importance. Different alternatives for the infrastructure initiative can then be examined in the SFM. The work with the Long List and the framework should be organised as a planning workshop where the influence of different stakeholder views (criteria selection and importance ordering) are taken into account. The following presentation of SFM concentrates on the framework based on a planning workshop organised with the purpose of informing the analytical part.

2.2 The main elements of the SUSTAIN Framework Model

The SUSTAIN Framework Model (SFM) consists of three main elements: the planning workshop, the long list of criteria and the SUSTAIN-DSS model (further elaborated in Salling and Pryn, 2015) as depicted in Figure 3 below. The purpose of the SFM is to assist the decision-makers in assessing complex decision problems, which usually involve multiple and often conflicting objectives (Leleur, 2012). Focus is on allowing for stakeholder involvement in the process in order to obtain informed and transparent decision support. Figure 3 depicts how the three elements interact under the framework. The SUSTAIN-DSS model featuring the three modules of cost-benefit analysis (CBA), feasibility risk assessment (FRA) and multi-criteria decision analysis (MCDA) makes use of input generated by the planning workshop to assess the criteria selected on the basis on the Long List.

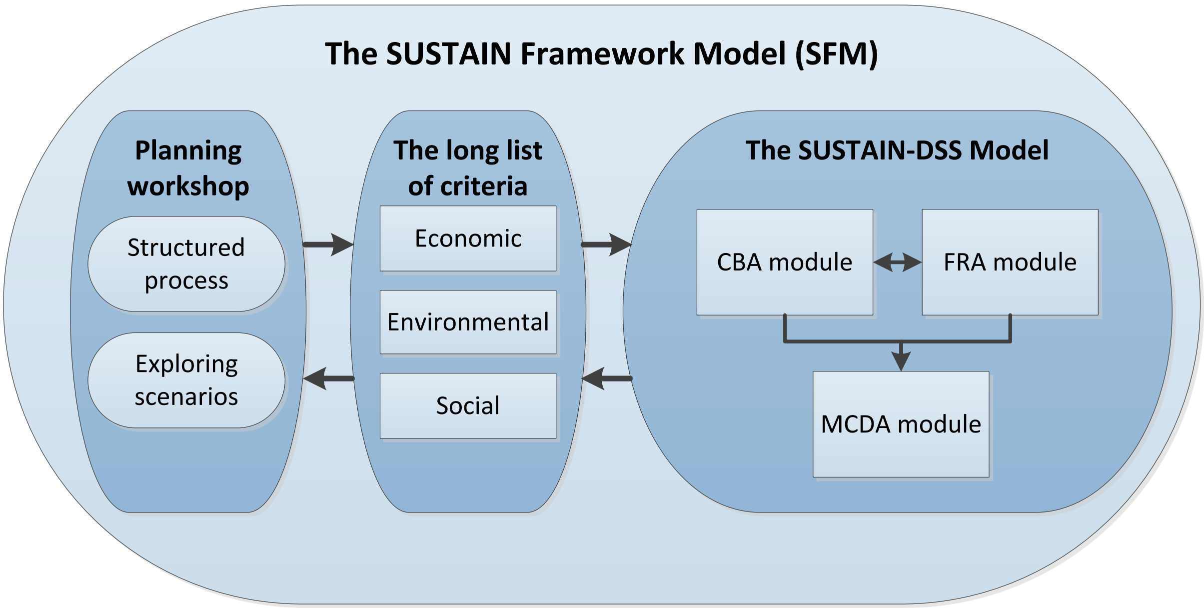

Figure 3. The SUSTAIN Framework Model indicated by its main elements.

CBA is the conventional part of the transport project appraisal. However, as the CBA does not account for uncertainties in e.g. demand forecasts and estimations of construction costs, the model provides an option for FRA using Monte Carlo Simulation (denoted as the A.1 Affordability criterion in Figure 2). Thus the CBA and FRA modules generate input to the MCDA module of the SFM, which is capable of addressing the non-monetised criteria. In contradiction to the CBA and FRA modules the MCDA module relies on input from stakeholders to assess the criteria and include them in the appraisal. The three modules of the SFM are described in the following sub-sections.

The CBA module

Cost-benefit analysis (CBA) is a common method for providing decision-makers with an economic assessment of the project alternatives expressed on a monetary scale. However, the issue of uncertainty appears as one of the main shortcomings of the method, apart from its inability to cover important strategic impacts such as economic development, land use, social cohesion etc. that are not easy to put a monetary value on. The CBA module is following the newest guideline on socio-economic analysis (published March 2015) by the Danish Ministry of Transport. It has furthermore been introduced in more depth e.g. in Salling and Banister (2009); Barfod and Salling (2015) and Salling and Pryn (2015).

The FRA module

As stated within the CBA above the major sources of uncertainty in connection with a large infrastructure project concern the construction costs and travel-time-related benefits (Demand), which have great importance for the long-term feasibility of the investment. The uncertainties can naturally be bigger in the context of a national infrastructure plan (or a regional/local) comprising of a list of individual projects rather than a single project.

The uncertainties underlying CBA are examined with Monte Carlo simulation by applying relevant probability distributions for these types of impact (Salling, 2008; Salling and Banister, 2009). This approach is based upon reference class forecasting and prospect theory (Kahneman and Tversky, 1979), which employs historical data from similar projects in the past to derive information about the possible outcome of the project being evaluated. The application and simulation of relevant probability distributions provides information that is presented in terms of a certainty graph (CG) for each alternative which shows the probability estimates of achieving at least the benefit-cost ratio (BCR) indicated as the CG's argument: $CG(x) = P(BCR \geq x)$. The certainty graph for each alternative is then used to set out and measure a criterion in the MCDA representing the affordability of the scheme.

The feasibility risk assessment provided in the framework model is presented as stand-alone results for any project alternatives to be appraised as suggested by the Danish Ministry of Transport (2015). Additionally, results stemming from such analysis reveal how well the examined scheme performs socio-economically, thus projects/alternatives substantially under-performing within this socio-economic context will normally be left out of any further analysis, such as the following multi-criteria decision analysis.

The MCDA module

The MCDA module offers an assessment with regard to the criteria that are not addressed by the CBA and FRA but still holds a potential of improving the decision support. Determining which criteria are relevant to include in the appraisal is a very important part of the process and should be handled with care as it may have a large effect on the final result. This means that the criteria should be comprehensive and relevant, and that precautions should be made to ensure that no criteria are overlapping. Thus a crucial part of the planning workshop is to make sure that the Long List of criteria is addressed properly so the relevant criteria for the specific case are chosen.

The model thus follows an approach where the CBA and/or the FRA results are treated as an additional criterion in the MCDA. Instead of using e.g. benefit-cost ratios (BCRs) as input, the certainty graphs (CGs) from the feasibility risk assessment are presented to the participants, and the assessment of the criterion is made based on these graphs. Hence, the risks and uncertainties will also be taken into account in the comprehensive appraisal.

Before starting the interaction process at the planning workshop it is, however, necessary to select a specific analytical approach. This selection can be regarded as a dynamic process which interacts with the process of the appraisal. A selection of techniques is offered as a part of the model, where the choice of technique then depends on the decision situation as described by

Barfod and Salling (2015): Are we dealing with well-defined options and criteria, or are we dealing with experts or persons with only a superficial knowledge about the decision problem? These different decision situations set different requirements and for this reason specific techniques with different characteristics have been identified for use in the model. In short it is recommended to use the SMARTER technique and the multiplicative AHP for criteria weights and alternative-scores respectively for basic users, while expert users should apply swing weights and the SMART technique (or multiplicative AHP) for weights and scores respectively (see Barfod and Salling (2015) for more information about the techniques). The module is, however, not limited to the techniques mentioned here and can be expanded in future developments.

Analysing scenarios

As presented in Figure 1 a generic overview of the transport planning process (a vision) together with understanding of the appraisal task lie behind the goals and objectives that inform both the determination and design of appropriate alternatives to enter the appraisal work. In the SUSTAIN Framework Model the vision as described above is included as scenarios specifically in terms of Business As Usual (BAU) and Sustainable Development (SD) scenarios as depicted in Table 2.

Table 2. Description of the two scenarios

Business as usual	Sustainable development
Improved infrastructure will result in more efficient land-bound connections that increase the overall accessibility in the transport network. Especially improved rail links will benefit the environment, contribute to alleviate congestion on the road network, increase the accessibility and potentially improve conditions for accelerated regional development in the countries and regions involved. A good and cost-effective transport system is a pre-condition for maintaining high economic growth and improving integration. There exists a common belief that a transition to 'sustainable' transport modes is possible, while at the same time meeting the needs indicated by transport forecasts.	The world's natural resources are limited, and there is a realisation that alternative energy sources cannot replace the fossil fuels to maintain the same standards as we have previously known. This means that both individual and freight transport must be based on more resource efficient modes. Concerning private transportation, mobility is now more of a luxurious good than a matter of cause. Instead planning is striving for accessibility to the necessary facilities. The big cities are becoming polycentric and more medium-sized cities are emerging. Due to the changed transportation pattern, there is a need to include and connect as many as possible of these cities in the sustainable transport corridors.

The two scenarios are different in nature as the BAU scenario is a descriptive scenario and based on know-how about past and current trends with no major changes being assumed. However, the SD is a normative scenario where the focus is on desirability of a development (Akgün et al., 2012). Both scenarios have been developed with reference to Banister's (2008) work on contrasting approaches for transport planning. Other scenarios can of course be tested, but as default the SFM is limited to these.

2.3 *Steps of the SUSTAIN Framework Model*

An examination of a case using the SFM should always be designed to accommodate the specific case, and the process must be divided into two main phases: (1) the preliminary problem structuring phase and (2) the interaction phase. The preliminary phase has its basis in problem structuring methods (see Barfod (2012b) for details). In the SFM the interaction phase is structured around a planning workshop. This enables a structured debate which is able to enrich the basis on which the decisions have to be made. Thus the aim of the planning workshop is to develop a common understanding of the decision problem between the participants, to create a sense of common purpose and achieve group commitment (Phillips and Bana e Costa, 2007). The concept consists of the main components: group processes, decision analysis and information technology. The group processes are assisted by an impartial facilitator guiding the participants though the different steps. As suggested by Barfod (2012a) such a process can be based on five steps leading the participants through the assessment. The steps are depicted in Figure 4 along with their methodological input and resulting output.

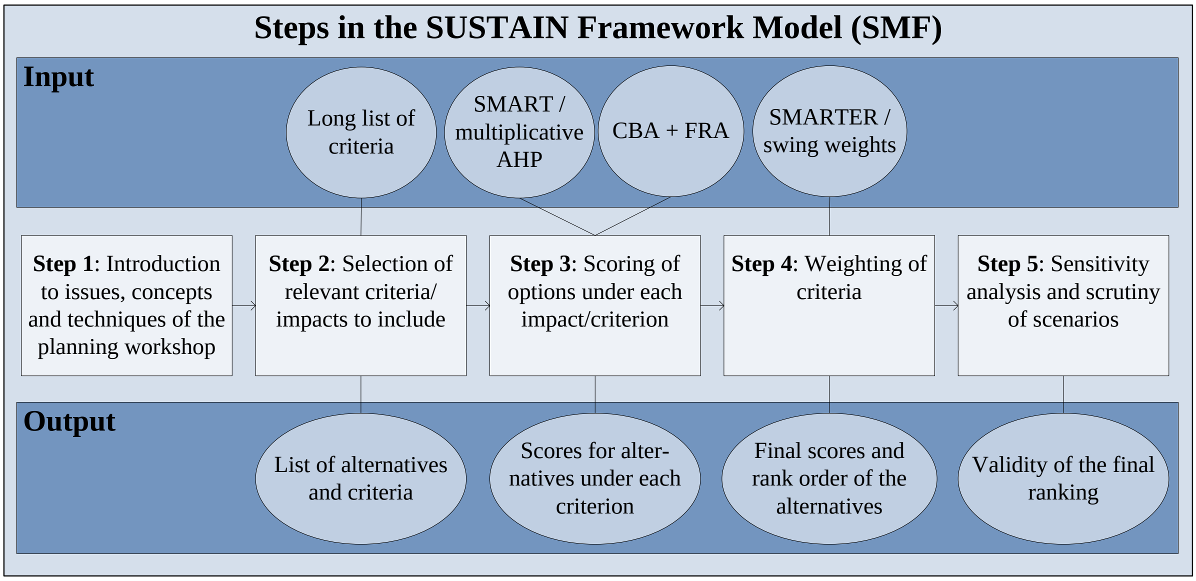

Figure 4. The 5 steps of the Framework model (adapted from Barfod (2012a) and Barfod and Salling (2015))

The first step introduces the concepts and methods to be used to reduce the "black-box" perception from the participants. In the second step the criteria relevant for the specific assessment task are identified from the Long List. It is the task of the participants to structure and reduce the list into a number of relevant criteria which are operational and all contribute to the segregation between options. When all criteria are identified the scoring of alternatives starts (step 3). As mentioned before different MCDA techniques can be applied in this step depending on the decision situation. In step 4 the weighting of the criteria is to take place (using one of the suggested techniques as explained under Section 2.2.3). This is considered to be a difficult task as participants may generate different weight sets based on their subjective opinions. Instead of trying to make the participants agree, it can be useful to examine these different weight sets as scenarios. Each scenario can include different criteria, and a full overlap of the criteria among the scenarios is not necessary. In case of full overlap of the criteria the scenarios can, however, still differ from each other due to different weighting of the criteria. Step 5 finally makes sure that proper sensitivity analysis is conducted and recommendations made based on the scrutinised scenarios. The process should be considered as iterative, and it is possible to go back in the process and revise assessments and test other scenarios if desired. However, the facilitator should make sure that this is only done if valid arguments can be made. It should not be seen as an invitation for participants to revise judgments until they present their favourite alternative as the most attractive.

Once all scenarios have been examined and total scores for all alternatives in each scenario are available it is possible to present the results across the examined scenarios and make an informed decision based on this. The result of the SFM is of course highly affected by the viewpoints of participants conducting the assessments along the process. Thus, a critical issue before commencing the process is to conduct a proper and thorough stakeholder analysis to identify the relevant participants.

3. Case study illustrations of the Framework

In order to illustrate the flexibility of the framework model theoretical applications are made to three previously disseminated case studies. The case studies contain examples of three different types of transport infrastructure projects ranging from a local fixed link crossing in the Danish town Frederikssund (Salling and Pryn, 2015), an EU corridor railway project linking the three Baltic countries to Poland and the rest of EU in the Rail Baltica case study (Ambrasaite et al., 2011) and finally a cross-border fixed link between Denmark and Sweden in the HH-connection case study (Barfod and Salling, 2015). These projects will now be described in a brief introduction after which each case study will be applied following the principles and modelling approach of the SFM. Each case study is referring to previous scientific papers where in depth descriptions and assessments have been performed. Finally, the only case study which actually has reached a political agreement is the project of a local fixed link in Frederikssund. The two other case studies have not reached any political agreement yet and are thus still to be considered as in the planning and preparation phase.

3.1 The Frederikssund fixed link connection

The planning of the Frederikssund fixed link connection has been an on-going project since the 1960's, but has recently come to an end after the government in March 2013 provided the legislative framework for a high bridge crossing south of Frederikssund, which is mainly to be funded through user charges (Pryn, 2013). The bridge is located in the area of Frederikssund in the northern part of the Greater Copenhagen area connecting the two banks of Roskilde Fjord, see Figure 5. The bridge has suffered from increasing congestion for several decades, but due to a location within a Natura2000 protected area, the construction of a new bridge has not been a straightforward issue. The bridge forms a local and regional link, but is not of national importance, and raising the money for a new connection has therefore been difficult (Pryn, 2013).

Figure 5. Location of Frederikssund and the bridge crossing Roskilde Fjord in Denmark

A set of alternative project solutions have been worked out whereby the first two are 'following' the conventional approach based in the 'predict-and-provide' regime (Owens, 1995) revolving around the number of (road) users the different alternatives can accommodate rather than inciting a break with the current development and encouraging a change in behaviour. The final two alternatives are 'controversial' alternatives proposed by the authors in order to scope and hence render evident the possibility of allowing for sustainable development as an alternative solution. Specifically, as discussed in Salling and Pryn (2015), a shift in paradigm is needed if a sustainable development scenario is to be implemented within transport planning (both on a local, regional and national level).

The four alternatives are as presented below (Salling and Pryn, 2015):

- Alternative 1 is identical with the officially decided solution and consists of a high level bridge located south of the city centre and funded through user charge.
- Alternative 2 is an expansion of the current bridge, also funded through user charge.
- Alternative 3 is a light rail link constructed via a new bridge connecting the western peninsula with the train station in Frederikssund.
- Alternative 4 is a service of free shuttle busses on the existing connection funded by user charges applied to other modes using the bridge.

The range of these alternatives explores the potential for such solutions within a sustainable planning (SD) scenario compared to a business as usual (BAU) scenario or current planning approach. Below the four alternatives are treated in accordance with sustainability having respectively an economic, a social and an environmental dimension.

As Alternative 3 and 4 are explorative scenario alternatives with strong sustainability emphasis, and since the actual assessment performed within the Frederikssund fixed link case study has been made with no full scale cost-benefit analysis, the criterion of Affordability is used as a qualitative pseudo entry for the economic dimension. Subsequently, all criteria from each of the three sustainability dimensions are explored and compared, illustrating the performance of the four alternatives within firstly the economic dimension, secondly the social dimension and finally the environmental dimension, see Table 3, 4 and 5. It should be noted that an assumption has been made in terms of assigning each criterion with the same weight, thus, they are split evenly depending on the number of criteria in the assessment.

Table 3. Normalised score of the alternatives assessed: economic sustainability dimension

The criteria	The criterion weight	The weighted alternative score within criterion			
		Alt 1	Alt 2	Alt 3	Alt 4
Affordability	0.20	1.74	1.11	0.54	0.97
Movement of goods	0.20	1.57	1.15	0.59	0.93
Efficiency	0.20	0.62	0.87	1.52	1.23
Resulting employment	0.20	0.71	0.71	1.74	1.15
Social costs	0.20	0.68	0.84	1.15	1.52
The total value:		0.81	0.66	0.97	1.93
The total normalized value:		0.19	0.15	0.22	0.44

Table 4. Normalised score of the alternatives assessed: social sustainability dimension

The criteria	The criterion weight	The weighted alternative score within criterion			
		Alt 1	Alt 2	Alt 3	Alt 4
Accessibility to employment	0.14	1.31	0.88	1.05	0.82
Accessibility to public services	0.14	1.19	0.78	1.05	1.03
Free movement	0.14	1.08	0.76	1.35	0.91
Mobility costs	0.14	0.84	0.72	1.10	1.49
Aesthetics	0.14	0.67	1.05	0.95	1.49
Equity concerns	0.14	0.71	0.91	1.08	1.45
Territorial cohesion	0.14	0.67	0.93	1.13	1.41
The total value:		0.45	0.34	1.90	3.45
The total normalized value:		0.07	0.05	0.31	0.56

Generally Table 3 shows a higher potential for Alternative 4, despite a poorer performance when assessed by the *affordability* criterion. Alternative 4 does not achieve the same time savings as the alternatives with increased capacity for the road traffic, but it is also not subject to the same construction costs as Alternative 1 and 2. Therefore results for Alternative 3 and 4 are mainly 'indicative' as compared to the results for Alternative 1 and 2.

Also within this assessment as presented in Table 4, Alternative 4 performs best, especially due to its possibility of travelling free of charge, which is considered a strong social asset. Alternative 3, however, also increases the social equity by offering new options directed at a wider range of user groups. Alternative 1 and 2 are not in line with the values presented for this social dimension, which is seen from their performance. The total scoring of this assessment is thus more distinct than the previous one with regard to the economic dimension.

Table 5. Normalised score of the alternatives assessed: environmental sustainability dimension

The criteria	The criterion weight	The weighted alternative score within criterion			
		Alt 1	Alt 2	Alt 3	Alt 4
Climate and global warming	0.11	0.75	0.87	1.08	1.41
Biodiversity	0.11	0.78	1.10	0.91	1.28
Consumption of renewable goods	0.11	0.81	0.93	1.08	1.24
Existing assets	0.11	0.81	0.94	1.02	1.28
Space consumption	0.11	0.72	1.36	0.89	1.14
Air pollution	0.11	0.75	0.91	1.10	1.33
Noise	0.11	0.79	0.87	1.02	1.41
Safety	0.11	0.87	1.02	1.02	1.10
Water quality	0.11	0.89	1.04	0.93	1.17
The total value:		0.13	0.96	1.02	7.98
The total normalized value:		0.01	0.10	0.10	0.79

The scoring of the alternatives within the environmental dimension strongly point at Alternative 4 as the alternative best meeting the environmental goals. Despite the uncertainty related to the assessment Alternative 4 with its low interference with, and sometimes even improvement of, the current conditions, is ranked very high. The results are not as unequivocal concerning the remaining alternatives though.

Subsequently following the principles behind the SFM is to arrive at a weighting of criteria in this case between the three outcomes from the dimensions. For the combination, the three dimensions are ranked according to the nested sustainability model (Joumard and Nicolas, 2010), i.e. the most long term dimension is nominated as the most important and so on, and assigned with surrogate weights following the SMARTER technique. By testing all criteria in the three dimensions using a swing weight approach a plausible variability of the dimension weights has been examined. This means that the economic dimension is ranked the lowest and receives a weight of 0.15, the social dimension is ranked in the middle and receives a weight of 0.32 and the environmental dimension ranked highest and receives a weight of 0.52. The combined results appear from Table 6.

Table 6. Normalised score of the alternatives assessed by the combined and ranked sustainability dimensions

The criteria	The dimension weight	The weighted alternative score within criterion			
		Alt 1	Alt 2	Alt 3	Alt 4
Economic	0.15	0.97	0.94	1.00	1.11
Social	0.32	0.77	0.71	1.23	1.49
Environmental	0.52	0.34	0.98	1.01	2.96
The total value:		0.26	0.65	1.24	4.90
The total normalized value:		0.04	0.09	0.18	0.70

The combination of the three assessments presents a clear picture of Alternative 4 being the alternative that best meets the sustainability framework, followed by Alternative 3, 2 and 1 respectively (Salling and Pryn, 2015).

3.2 *The Rail Baltica railway corridor*

The Rail Baltica project aims at ensuring a safe, fast and high quality connection between the Baltic States and the major economic, administrative and cultural centres of Western Europe (Ambrasaite et al., 2011). The Baltic rail system is currently incompatible with mainland European standards (due to among others the gauge standard), thus the goal is to link Helsinki – Tallinn – Riga – Kaunas – Warsaw continuing to Berlin (see Figure 6). Until Estonia, Latvia and Lithuania joined the European Union, the issue was not considered a high priority. Now, within the European Union, there is a full consensus that the three countries need to be fully integrated into the wider European rail transport system.

Figure 6. Overview of the Rail Baltica corridor

Four alternatives have been identified based on considering various technical and environmental aspects including an initial cost-benefit analysis as illustrated in Table 7 (Ibid.).

Table 7. Four alternatives, costs (2010 price level), distance, journey time and average speed

Alternative	Construction costs (mio €)	BCR	Distance (km)	Passenger/Freight	
				Journey time (hrs.)	Avg. speed (km/h)
Alternative 1	4,882	1.75	701	4h08m / 10h23m	170 / 68
Alternative 2	5,077	1.26	788	6h08m / 11h34m	128 / 70
Alternative 3	5,508	1.40	791	4h49m / 11h10m	165 / 71
Alternative 4	5,328	1.07	858	6h44m / 11h53m	127 / 72

From the results of the CBA Alternative 1 should be preferred with a BCR on 1.75. However, an important appraisal question, and the rationale behind the formulation of the SFM, is: *Are there any strategic elements that are not included in the CBA, which could provide an argument for selecting another alternative*? The following Table 8 illustrates the application and modelling procedure from the SUSTAIN framework model. First the five step process (Figure 4) is applied, where the criteria to base the assessment on is selected in step 2. Table 8 shows the criteria selected for the assessment of the SD scenario (as discussed in Table 2) ranked in accordance with the importance that the participants agreed on in a conducted planning workshop. The criteria are listed in random order, and the numbering corresponds to the denotations in Figure 2.

Table 8. Criteria selection for the Sustainable Development (SD) scenario

Criteria	Explanation
B.1 Climate and global warming	How much does the alternative contribute to reduction of carbon dioxide, methane, nitrous oxide and ozone? To what degree does it use low carbon fuels or carbon free energy sources?
B.4 Existing assets and resources	How much does the alternative involve the use of existing assets?
C.2 Accessibility to public services	How much does the alternative contribute to ease of movement of public travellers inside the region?
A.2 Movement of goods w. special emphasis on location of companies and logistics centres	How much does the alternative affect better efficiency of companies resulted by a better location? How much does it contribute to establishment of new businesses?
A.3 Efficiency w. special emphasis on the competition on transport markets	How much impact does the alternative have on competition on the transport market in terms of services, prices, availability, comfort and punctuality?
C.5 Townscape and land-use aesthetics	How much does the alternative contribute to preservation of existing townscapes?
C.8 Equity concerns w. special emphasis on the social inclusion and participation	How much does the alternative contribute to or promote social inclusion in any territories?
A.1 Affordability in terms of so-called certainty values from the FRA	How robust and certain is the socio-economic performance based on certainty graphs based on the variability of transport demand and construction costs.

The selection and ranking of Short List criteria is made based on the contribution of each particular criterion as regards the vision of sustainable development. Therefore, when e.g. the criterion *Accessibility by public transport* is included in the SD scenario, emphasis is on how the alternatives contribute to increase people's efficiency in travelling. Three criteria from the economic pillar of the Long List are selected in the SD scenario: A.2, A.3 and A.1. Two environmental criteria are selected: B.1 and B.4. Finally three social criteria are selected: C.2, C.5 and C.8, arriving at 8 criteria which make up the SD scenario. Due to the composition of the group of participants within the conducted planning workshop, who could be regarded as basic users of decision analytic techniques, it was chosen to use the SMARTER technique for deriving criteria weights and the multiplicative AHP for determining scores for the alternatives (Barfod, 2012a).

Table 9 presents the results from the pairwise comparisons made in the SFM, where the best performing alternative under each criterion is highlighted. Moreover the weights indicated by the SMARTER technique are assigned to the criteria, and total scores are calculated for each alternative.

The results show that while Alt. 1 is the most favourable alternative according to the CBA (A.1), Alt. 4 is achiving a slightly higher score than Alt. 1 in the SD scenario. However, the Affordability of the SD scenario reveals that this ranking is highly sensitive as only minor changes in the weighting on several of the criteria can tip the result. Because of this further more detailed analyses need to be made before a decision can be taken.

The presentation of results across the scenarios can be carried out not just for the consensus-values given as input to the analytical modelling but also for each of the stakeholders represented, based on their input when not being affected by seeking to make consensus compromises.

Table 9. Assessment scores - Sustainable development

Criteria (weights)	Alt 1	Alt 2	Alt 3	Alt 4
A.1 Affordability (0.03)	0.77	0.20	0.16	0.01
A.2 Location of companies and logistics centers (0.14)	0.30	0.15	0.04	0.50
A.3 Competition on transport markets (0.11)	0.28	0.03	0.67	0.02
B.1 Climate and global warming (0.23)	0.64	0.11	0.23	0.02
B.4 Existing assets and resources (0.20)	0.02	0.11	0.11	0.76
C.2 Accessibility to public services (0.17)	0.18	0.09	0.02	0.71
C.5 Townscape and land-use aesthetics (0.08)	0.02	0.38	0.07	0.53
C.8 Social inclusion and participation (0.05)	0.51	0.11	0.03	0.36
Total score	0.30	0.20	0.18	0.32

3.3 The HH-Connection between Denmark and Sweden

The case concerns a new complementary fixed link connection between Denmark and Sweden. Regionally, the proposed connection is expected to create a substantial increase in trade, education and workplace related benefits. Ultimately it is expected that a fixed link with increased commuter traffic across the border will result in a common labour and residential market (Salling and Leleur 2017; Barfod and Salling, 2015). The case which is commonly referred to as the HH-Connection is located approximately 50 km north of the existing fixed link across Oresund (see Figure 7).

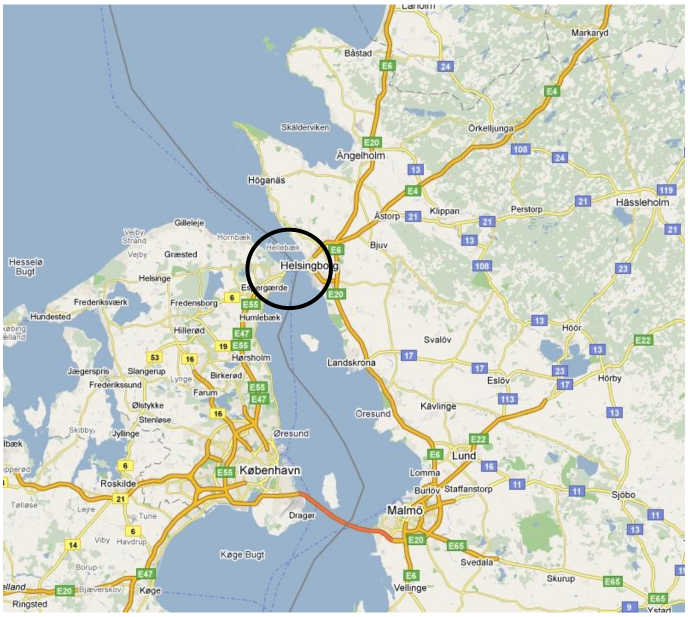

Figure 7. The proposed new fixed link between Elsinore (Helsingor - Denmark) and Helsingborg (Sweden): the HH-Connection (from Google Maps)

The current situation with a ferry service is referred to as the base scenario where the proposed alternatives will substitute the ferries with a fixed link where three alternatives are considered, see Table 10.

In the following the appraisal of the three alternatives of the HH-connection will be carried out in accordance with the steps of the SFM with a focus on the results from the SD scenario. The CBA and FRA, which are input to Step 3 in the process (Figure 4), can with advantage be conducted before commencing the planning workshop. These calculations are initially based on traffic model calculations and are consequently time consuming to perform.

Table 10. The proposed three alternatives for the HH-Connection with construction costs in million DKK (adapted from Barfod and Salling, (2015))

HH-Connection (alternatives)	Description (Alignment of connection	Cost (mio DKK)
Alternative 1	Tunnel for rail (2 tracks) person traffic only	9,500
Alternative 2	Tunnel for rail (2 tracks), passenger trains only + tunnel for vehicles (2x2 lanes)	24,500
Alternative 3	Tunnel for rail (2 tracks), passenger trains + tunnel for vehicles (2x2 lanes) + tunnel for rail (single track), goods trains	32,500

In accordance with the Danish manual for socio-economic analysis (DMT, 2015) the CBA includes estimations of the construction costs, time savings, vehicle operating costs, maintenance and operating costs of the infrastructure, environmental consequences (CO_2 and local emissions), and ticket revenue. Based on this a set of deterministic BCRs and NPVs for each alternative are determined as depicted in Table 11. The embedded uncertainties are afterwards treated through stochastic calculations where a set of reference classes respectively for railway and fixed link projects are used. Based on the FRA simulations a set of certainty graphs are produced as depicted in Figure 8.

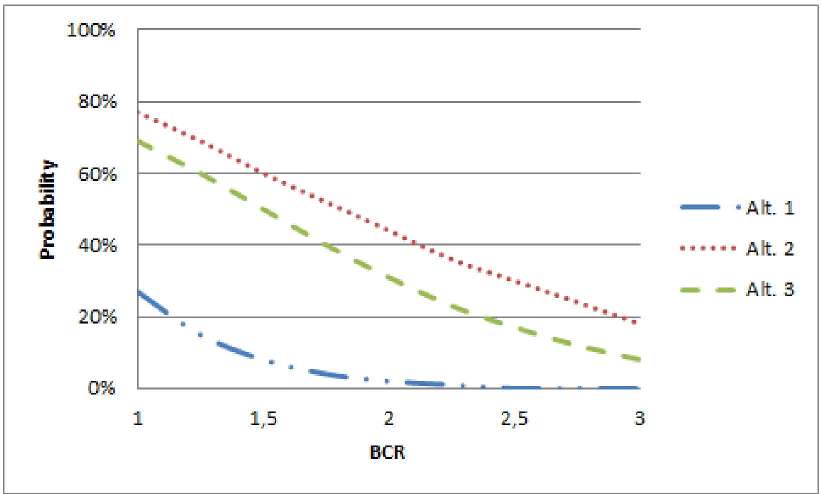

Figure 8. Certainty graphs for the three alternatives

The points where the graphs cross the y-axis indicate the probability of achieving a BCR higher or equal to 1.00, which indicates the robustness of the alternative. However, none of the alternatives in the case are 100 % certain of being feasible, which indicates that even though the conventional CBA produces feasible results for all three alternatives, the certainty and included risk for the CBA returns only certainty of feasible alternatives respectively with 27%, 77% and 69% probability. The economic index values along with the calculated certainty values (CV) are listed in Table 11.

Table 11. Economic index values and certainty values (CV) for the three alternatives

Alternative	BCR	NPV (mio DKK)	CV
Alternative 1	1.23	2,657	27%
Alternative 2	2.38	40,506	77%
Alternative 3	1.99	38,518	69%

In the second step of the process SD criteria are selected from the Long List and ranked in order of importance by the participants in the planning workshop (see Table 12 for the SD scenario).

Table 12. Criteria selection for the Sustainable Development scenario

Criteria	Explanation
A.4: Resulting Employment and Effect on Tourism	The alternatives' potential for contributing to the economic development in the Oresund region. In order to obtain economic development in the northern part of the Oresund region the area should become more attractive both to housing, business and tourism.
A.1: Affordability	The overall economic performance of the alternative. The main indicator is the CV based on the results stemming from the CBA and FRA.
C.3: Free Movement (Travel Freedom)	Accessibility for both cars and public transportation. This is represented by the increased mobility potential that the commuters obtain (they can cover more geographic space using the same time as previously).
B.1: Climate and Global Warming	The alternatives' potential for promoting the green transport corridors which support the EU's agenda towards decarbonising transport while emphasising the need for efficient logistics.
A.2: Movement of Goods	The impact on the efficiency, punctuality, security, co-modality and risk in the logistic chains. A new connection can help to expand companies' clientele, and at best, it can result in that some companies can close down a production area, thereby saving money.
B.5: Space Consumption	The visual environment in the towns of Elsinore and Helsingborg. The type of the land-based facilities and their geographical placement will for this reason be in focus.

Three criteria from the economic pillar of the Long List are selected in the SD scenario: A.4, A.1 and A.2. Two environmental criteria are selected: B.1 and B.5. Finally one social criterion is selected: C.3, arriving at 6 criteria which make up the SD scenario. Due to the composition of the participating group the SMARTER technique is selected for deriving criteria weights and the multiplicative AHP is used for assigning scores to the alternatives. Table 13 below presents the results from the pairwise comparisons made in the SFM together with the weights for the criteria as implied by the ranking in Table 12.

Table 13. Assessment scores - Sustainable development

Criteria (weights)	Alt 1	Alt 2	Alt 3
A.1 Affordability (0.03)	0.01	0.85	0.13
A.2 Location of companies and logistics centers (0.14)	0.00	0.06	0.94
A.4 Resulting employment and effect on tourism (0.30)	0.01	0.28	0.71
B.1 Climate and global warming (0.23)	0.00	0.02	0.98
B.5 Space consumption (0.04)	0.00	0.71	0.28
C.3 Free movement (travel freedom) (0.19)	0.00	0.28	0.71
Total value score	0.00	0.31	0.68

From Table 13 Alternative 1 can be dismissed from the analysis with poor results on all criteria. Alternative 2 performs well on two criteria (A.1 and B.5), but is outranked by Alternative 3 on all other criteria. If the decision was to be based on a conventional CBA A.1 would be the only criterion and alternative 2 would be chosen. However, including a wider set of non-monetary decision criteria in the evaluation scheme actually produced a shift between alternatives that was not captured in the CBA/FRA analyses, and alternative 3 then becomes the obvious choice.

3.4 Case result comparisons

This section has illustrated three case studies applying the SUSTAIN Framework Model (SFM) and the context of a sustainable development scenario. Clearly, project appraisal following a business-as-usual approach leaves very little room for inclusion of a wider set of planning criteria in the decision-making process. Whether the above case studies generally provide a valid approach for national sustainable transport planning clearly needs further examination. However, it is clear that just by including planning criteria as presented in Figure 2 and seeking to accommodate 'an alternative approach' as presented in Table 1 provides the decision-makers with a powerful tool to address and assess sustainability. Transport planning and decision support in the context of sustainable development necessitates a rethinking on how to provide sound decision support. Specifically, the challenge is to seek national and global consensus on how to embed such non-quantifiable effects in transportation planning and policy-making towards a sustainable transport development without comprising the overall objective of accessibility.

The development of the SUSTAIN framework model
The SUSTAIN Framework Model (SFM) was developed from a basis only looking into CBA and feasibility risk assessment as depicted in the UNITE-DSS model (Salling and Leleur, 2015). The decision support system as well as the overall framework model is flexible as is can be tailor-made to solve problems or projects ex-ante covering all types of transport modes and means as illustrated in the three case studies. There seems to be a widespread consensus that conventional cost-benefit analysis is often not sufficient when it comes to transport evaluation. However, only few governments seek to incorporate national sustainable transport planning criteria systematically in their respective standardised national manuals for transport evaluation. SUSTAIN provides a systematic approach to include sustainable development consideration within ex-ante based cost-benefit analysis in accordance with the SUSTAIN Framework model. This has been done by implementing the development stages shown from left to right in Figure 9.

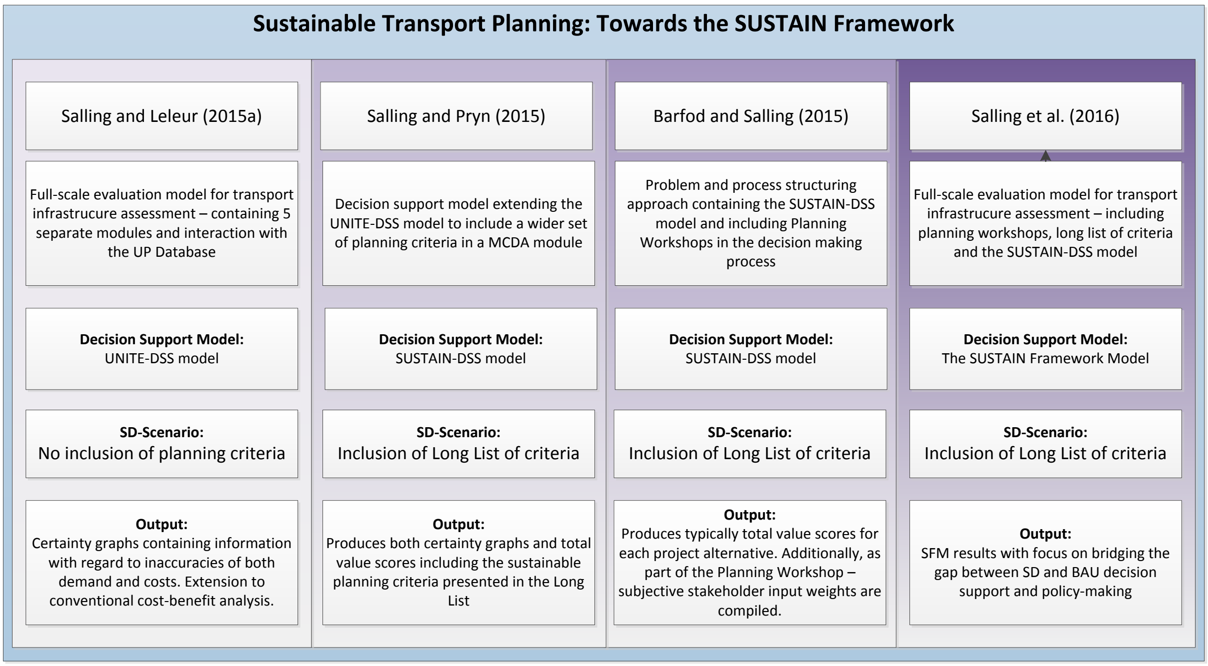

Figure 9. Overview of the development stages of the SUSTAIN Framework model

4. Conclusion and Perspective

A key concern with development of the SUSTAIN Framework Model has been to identify an effective methodology to undertake comprehensive evaluation with the purpose of supporting sustainable transport planning. This complex challenge can be met in an appraisal methodology with an approach which involves MCDA to embrace various and often conflicting criteria. Specifically the MCDA module 'builds on top' of CBA/FRA modules based upon accepted socio-economic analyses and quantitative risk assessment, with the latter made use of to incorporate uncertainty of the SFM results. A working paper (Leleur, 2015) has been produced to communicate results in a less technical way.

The SFM approach has the advantage of making conflicting views among stakeholders and/or decision-makers more explicit, thereby permitting better monitoring both during and after the assessment process. In MCDA, distributional issues are made explicit since the processes of allocating weights and scores are separated. Decision-makers are therefore free to choose criteria from the Long List and give relatively more weight to the criteria they consider important. Distributional conflicts can be addressed in MCDA through the examination of different scenarios.

Finally, the framework model has been set out to make it possible to conduct appraisal studies based on a comprehensive range of objectives relevant for national sustainable transport planning. As demonstrated by the case examples it can be used in a flexible way and adapted to the specific appraisal problem. An important key point that is shown by all three case studies is that a wider assessment (using the SUSTAIN framework model) may lead to a shift in the most preferred option as compared with assessment based on CBA only. The cases concern classic infrastructure planning examples, but the approach can easily be adapted to also assess policies and interventions of different kinds.

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